National Aeronautics and
Space Administration

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GeoSTAR

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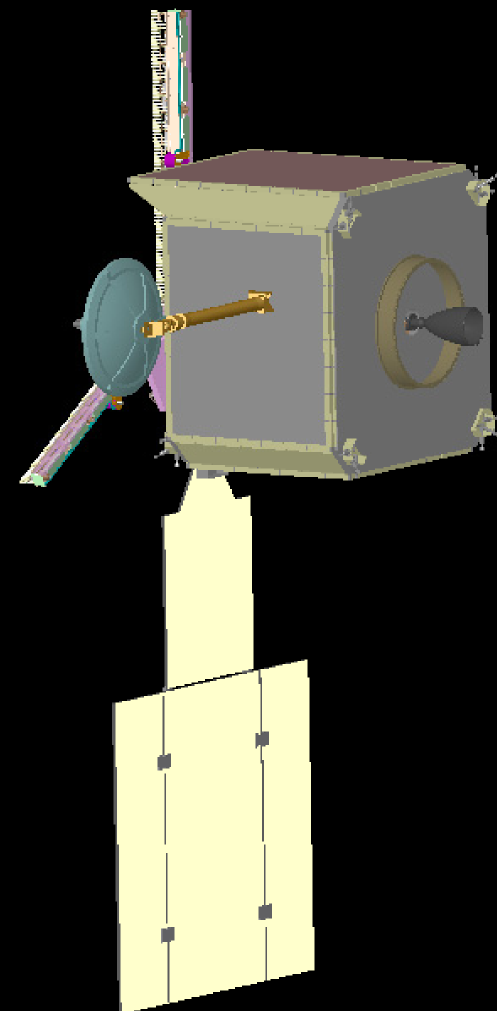


SPIE 4th International Asia-Pacific Environmental Remote Sensing Symposium

Honolulu, Hawaii
November 8-11, 2004

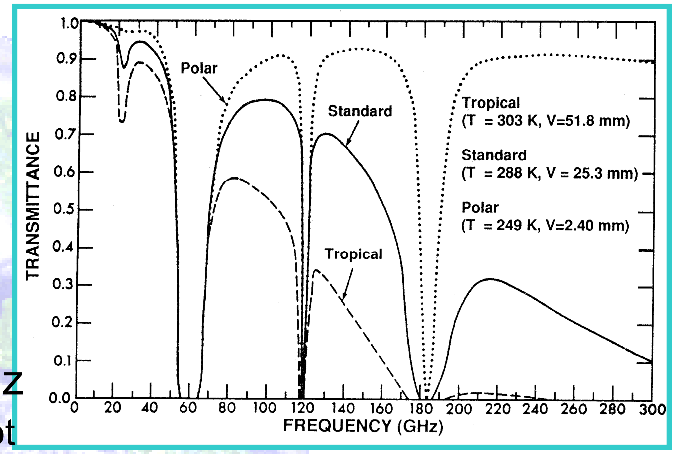
Summary

- **GeoSTAR is a microwave sounder intended for GEO**
  - Ground-based prototype under development
  - Space-based version can be developed in time for GOES-R
  - Configuration suitable for MEO is also under study
- **Functionally equivalent to AMSU**
  - Tropospheric T-sounding @ 50 GHz with ≤ 50 km resolution
    - *Stand-alone all-weather temperature soundings*
    - Cloud clearing of IR sounder
  - Tropospheric q-sounding @ 183 GHz with ≤ 25 km resolution
    - *Stand-alone all-weather water vapor/liquid water soundings*
    - *Rain mapping*
    - *Tropospheric wind profiles* (-New product, only feasible from GEO)
- **Using *Aperture Synthesis***
  - Also called Synthetic Thinned Array Radiometer (STAR)
  - Also called Synthetic Aperture Microwave Sounder (SAMS)

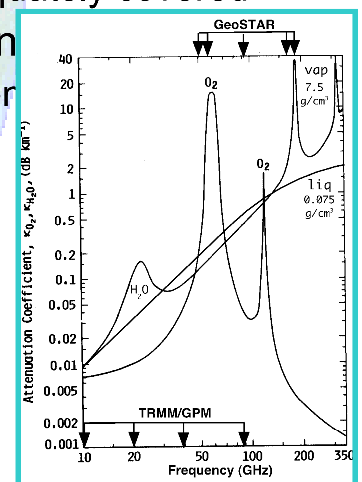
Why?

- **GEO/MEO sounders complement LEO sounders**
  - LEO: Global coverage, but poor temporal resolution; high spatial res. is easy
  - GEO: High temporal resolution and coverage, but only hemispheric non-polar coverage; high spatial res. is difficult
  - MEO: Global coverage and high temporal resolution (assuming constellation)
  - Requires equivalent measurement capabilities as now in LEO: IR + MW
- **Enable full sounding capability from GEO/MEO**
  - Complement primary IR sounder with matching MW sounder
    - Until now not feasible due to very large aperture required (~ 4-5 m dia. in GEO)
  - Microwave provides cloud clearing information
    - Requires T-sounding through clouds
    - Must reach surface under all atmospheric conditions
- **Stand-alone IR sounders are only marginally useful**
  - Can sound down to cloud tops ("clear channels")
  - Can sound in clear areas ("hole hunting")
    - Clear scenes make up < 2% globally at AMSU resolution (50 km)
  - Both exclude active-weather regions & conditions

Measurement Requirements



- **Radiometric sensitivity**
  - Must be no worse than AMSU (≤ 1 K)
- **Spatial resolution**
  - At nadir: ≤ 50 km for T; ≤ 25 km for q
- **Spectral coverage**
  - Tropospheric T-sounding: Must use 50-56 GHz
    - Note: Higher frequencies (118 GHz, etc.) cannot penetrate to the surface everywhere
    - Bottom 2 km is the most important/difficult part and must be adequately covered
  - Tropospheric q-sounding: Must use 183 GHz (AMSU-B chann
    - Note: Higher frequencies (325 or 450 GHz) cannot penetrate ever moderate atmospheres
  - Rain by scattering: Best to use 183 GHz (AMSU-B channels)
- **Temporal coverage from GEO**
  - T-sounding: Every 1-2 hours @ 50 km resolution
  - Q-sounding: Every 30 minutes @ 25 km resolution
- **There are no short-cuts!**
  - Using high frequencies to obtain small aperture & high resolution is not feasible

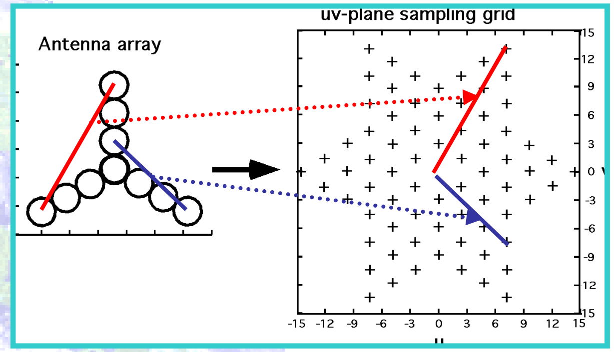


Functionality & Benefits of GeoSTAR

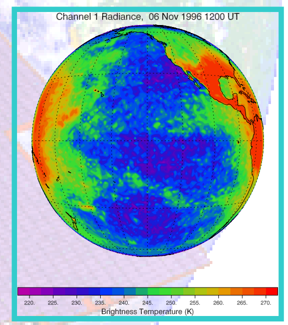
- **All-weather soundings @ 2-4 km vertical resolution**
  - Full hemisphere @ ≤ 50/30 km every 30-60 min (continuous) - easily improved
  - Standalone soundings; Also complements any GEO IR sounder
- **Rain**
  - Full hemisphere @ ≤ 30 km every 30 min (continuous) - easily improved
  - Measurements: scattering from ice caused by precipitating cells
  - Real time: full hemispheric snapshot every 30 minutes or less
- **Tropospheric wind profiling**
  - Surface to 300 mb; adjustable pressure levels
  - Primarily horizontal winds vectors (at pressure levels)
  - Very high temporal resolution possible
  - Vertical winds may also be feasible - requires some research
- **Rapid-cycle NRT storm tracking**
  - Scattering signal from hurricanes/convection detectable in < 5 minutes
  - Switch to detect/track mode -> Update every 5 minutes (continuous)

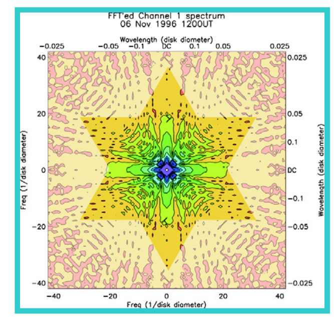
GeoSTAR System Concept

- **Concept**
  - Sparse array employed to synthesize large aperture
  - Cross-correlations -> Fourier transform of Tb field
  - Inverse Fourier transform on ground -> Tb field
- **Array**
  - Optimal Y-configuration: 3 sticks; N elements
  - Each element is one I/Q receiver, 3λ wide (2 cm @ 50 GHz)
  - Example: N = 100 ⇒ Pixel = 0.09° ⇒ 50 km at nadir (nominal)
  - One “Y” per band, interleaved
- **Other subsystems**
  - A/D converter; Radiometric power measurements
  - Cross-correlator - massively parallel multipliers
  - On-board phase calibration
  - Controller; accumulator -> low D/L bandwidth



Receiver array & Resulting uv samples





Example: AMSU-A ch. 1

Aperture Synthesis Is Not New

Very Large Array (VLA) at National Radio Astronomy Observatory (NRAO)

In operation for many years

Others Are Developing STAR for Space

ESA's Soil Moisture and Ocean Salinity (SMOS)

L-band system under development - Launch in 2007

What GeoSTAR Measures

- **Visibility measurements**
  - Essentially the same as the spatial Fourier transform of the radiometric field
  - Measured at fixed uv-plane sampling points - One point for each pair of receivers
  - Both components (Re, Im) of complex visibilities measured
  - Visibility = Cross-correlation = Digital 1-bit multiplications @ 100 MHz
  - Visibilities are accumulated over calibration cycles —> Low data rate
- **Calibration measurements**
  - Multiple sources and combinations
  - Measured every 20-30 seconds = calibration cycle
- **Interferometric imaging**
  - All visibilities are measured simultaneously - On-board massively parallel process
  - Accumulated on ground over several minutes, to achieve desired NEDT
  - 2-D Fourier transform of 2-D radiometric image is formed - *without scanning*
- **Spectral coverage**
  - Spectral channels are measured one at a time - LO tunes system to each channel

Calibration

- **GeoSTAR is an *interferometric* system**
  - Therefore, *phase calibration* is most important
  - System is designed to maintain phase stability for tens of seconds to minutes
  - Phase properties are monitored beyond stability period (e.g., every 20 seconds)
- **Multiple calibration methods**
  - Common noise signal distributed to multiple receivers —> complete correlation
  - Random noise source in each receiver —> complete de-correlation
  - Environmental noise sources monitored (e.g., sun's transit, Earth's limb)
  - Occasional ground-beacon noise signal transmitted from fixed location
  - Other methods, as used in radio astronomy
- **Absolute radiometric calibration**
  - One conventional Dicke switched receiver measures "zero baseline visibility"
    - Same as Earth disk mean brightness temperature (= Fourier offset)
  - Also: compare with equivalent AMSU observations during over/under-pass
  - The Earth mean brightness is highly stable, changing extremely slowly

GeoSTAR Data Processing

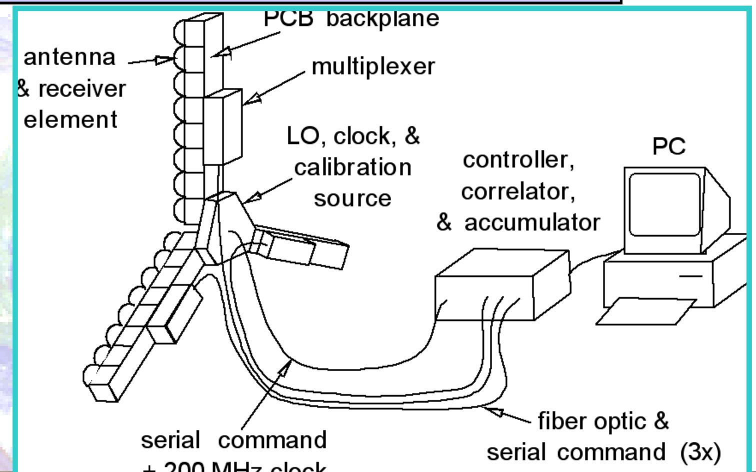
- **On-board measurements**
  - Instantaneous visibilities: high-speed cross-correlations
  - Accumulated visibilities: accumulated over calibration cycles
  - Calibration measurements
- **On-ground image reconstruction**
  - Apply phase calibration: Align calibration-cycle visibility subtotals
  - Accumulate aligned visibilities over longer period —> Calibrated visibility image
- **On-ground image reconstruction**
  - Inverse Fourier transform of visibility image, for each channel
  - Complexities due to non-perfect transfer functions are taken into account
- **On-ground geophysical retrievals**
  - Conventional approach
  - Applied at each radiometric-image grid point

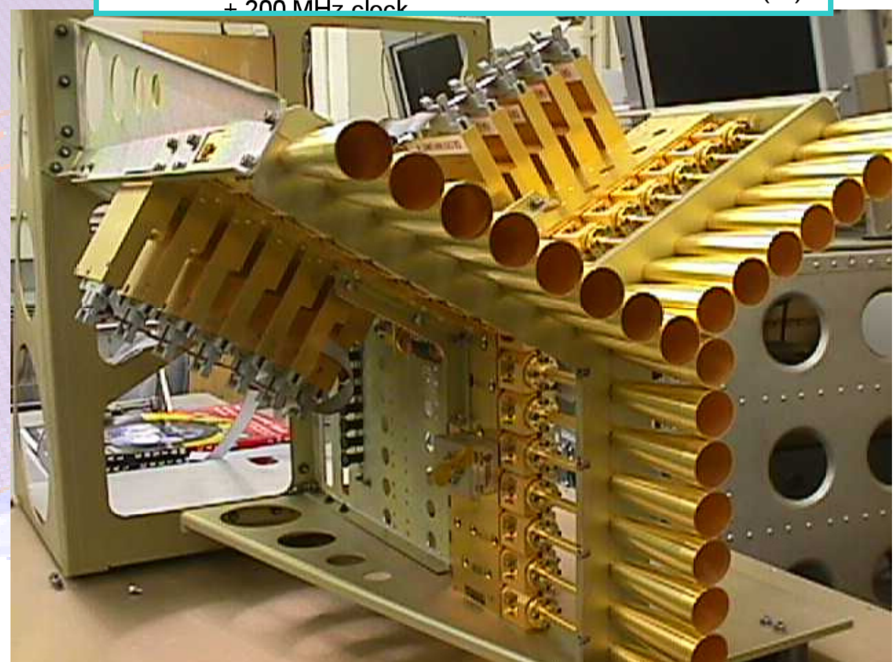
Technology Development

- **MMIC receivers**
  - Required: Small (2 cm wide ‘slices’ @ 50 GHz), low power, low cost
  - Status: Receivers off-the-shelf @ < 100 GHz; Chips available up to 200 GHz
- **Correlator chips**
  - Required: Fast, low power, high density
  - Status: Real chips developed for IIP & GPM; Now 0.5 mW per 1-bit @ 100 MHz
- **Calibration**
  - Required: On-board, on-ground, post-process
  - Status: Will implement & demo GEO/SAMS design in Proto-GeoSTAR
- **System**
  - Required: Accurate image reconstruction (Brightness temps from correlations)
  - Status: Will demonstrate capability with Proto-GeoSTAR
- **Related efforts: Rapidly maturing approach & technology**
  - European L-band SMOS now in Phase B; to be launched ~2007
  - NASA X/K-band aircraft demo (LRR): candidate for GPM constellation
  - NASA technology development efforts (IIP, etc.); various stages of completion

GeoSTAR Prototype Development

- **Objectives**
  - Technology risk reduction
  - Develop system to maturity and test performance
  - Evaluate calibration approach
  - Assess measurement accuracy
- **Small, ground-based**
  - 24 receiving elements - 8 (9) per Y-arm
  - Operating at 50-55 GHz
  - 4 tropospheric AMSU-A channels: 50.3 - 52.8 - 53.71/53.84 - 54.4 GHz
  - Implemented with miniature MMIC receivers
  - Element spacing as for GEO application (3.5 λ)
  - FPGA-based correlator
  - All calibration subsystems implemented





GeoSTAR vs. Real-Aperture Approach

Feature	GeoSTAR	Real aperture
Aperture size	Any size	Limited
Scanning	No scanning	Mechanical scanning
Spatial coverage	Full disk	Limited
Spectral coverage	One array per band	One antenna/N receivers
Accommodation	Easy	Difficult
Power consumption	Moderate	Moderate
Platform disturbance	None	High
Technology risk	High	Moderate

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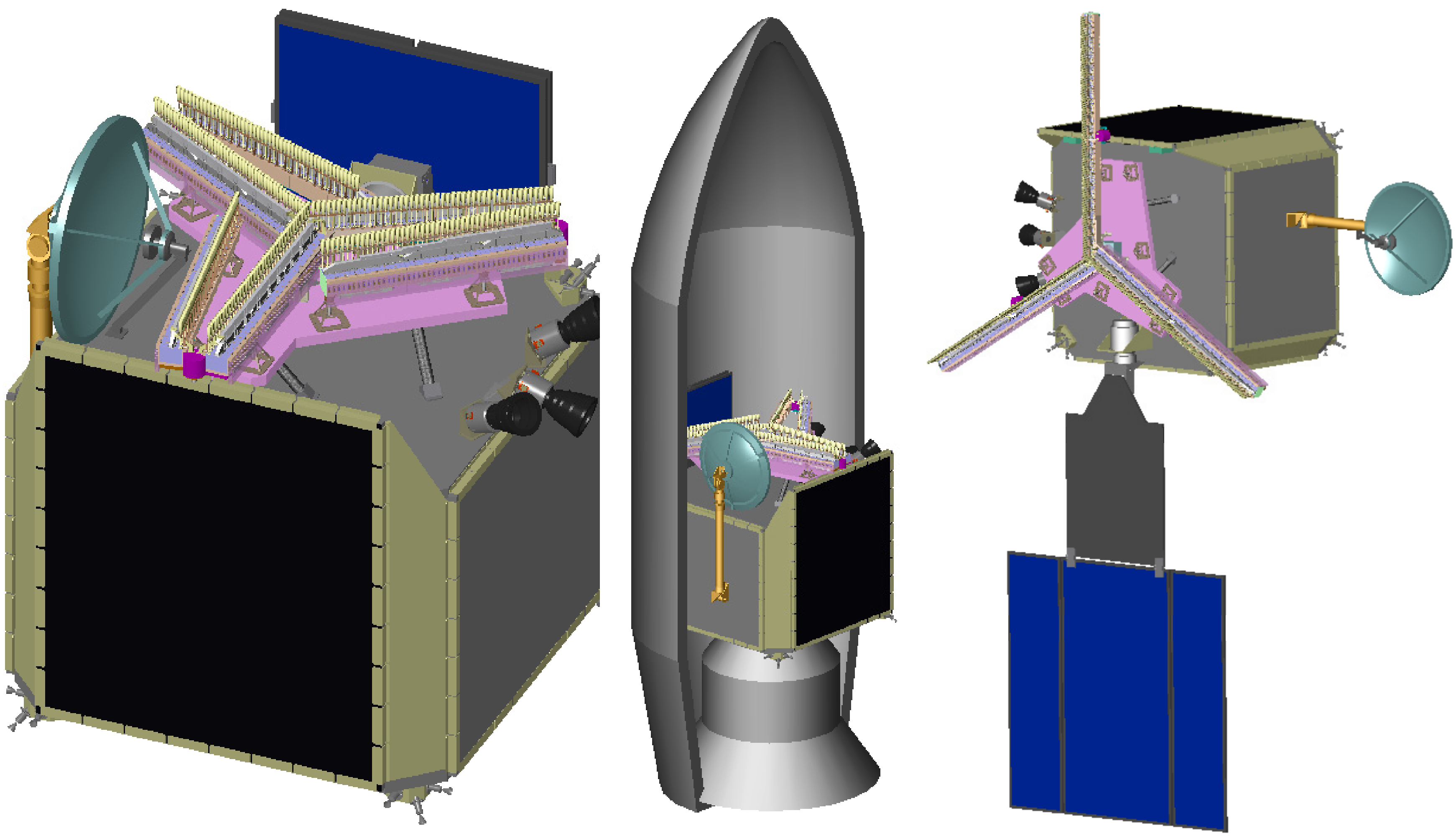
Accommodation Studies



Array arms folded for launch **Stowed in Delta fairing** **Deployed on-orbit**

Ball Aerospace

GEO Roadmap

- **Prototype: 2003-2005**
  - Functional system expected ready in 6 months
  - Fully characterized in < 2 years
- **Further technology development: 2005-2008**
  - Develop 183-GHz multiple-receiver modules
  - Develop efficient radiometer assembly & testing approach
    - Reduce cost per receiver
  - Migrate correlator design & low-power technology to rad-hard ASICs
    - **Correlator state of the art is now ~ 0.1 mW/corr!**
      - 2-bit ASIC chip using 0.5 mW/corr is now being tested by U.Mich/GSFC
    - Correlator power consumption is rapidly becoming a non-issue
  - Develop signal distribution, thermal control & other subsystems.
- **Space demo: ~2008-2012**
  - Ready for Phase B in 2008
  - Ready for launch in 2012

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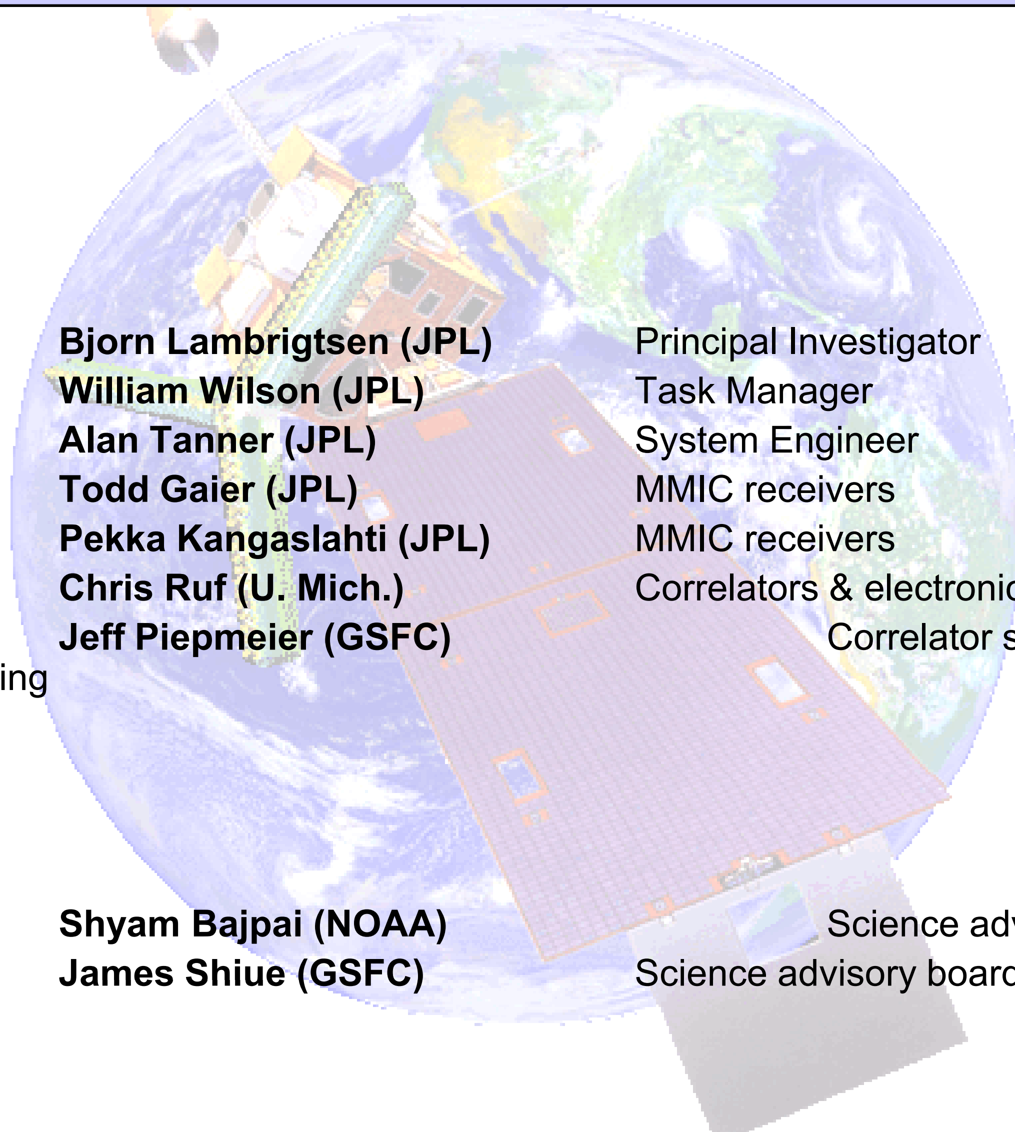
The GeoSTAR Team



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